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Long-term monitoring of the short period SU UMa-type dwarf nova, V844 Herculis

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Abstract

We report on time-resolved CCD photometry of four outbursts of a short-period SU UMa-type dwarf nova, V844 Herculis. We successfully determined the mean superhump periods to be 0.05584(64) days, and 0.055883(3) for the 2002 May superoutburst, and the 2006 April-May superoutburst, respectively. During the 2002 October observations, we confirmed that the outburst is a normal outburst, which is the first recorded normal outburst in V844 Her. We also examined superhump period changes during 2002 May and 2006 April-May superoutbursts, both of which showed increasing superhump period over the course of the plateau stage. In order to examine the long-term behavior of V844 Her, we analyzed archival data over the past ten years since the discovery of this binary. Although photometry is not satisfactory in some superoutbursts, we found that V844 Her showed no precursors and rebrightenings. Based on the long-term light curve, we further confirmed V844 Her has shown almost no normal outbursts despite the fact that the supercycle of the system is estimated to be about 300 days. In order to explain the long-term light curves of V844 Her, evaporation in the accretion disk may play a role in the avoidance of several normal outbursts, which does not contradict with the relatively large X-ray luminosity of V844 Her.

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (V844 Herculis) — stars: novae, cataclysmic variables — stars: oscillations

1. Introduction

Dwarf novae belong to a subclass of cataclysmic variable stars that consist of a white dwarf (primary) and a late-type star (secondary). The secondary star fills its Roche lobe and transfers mass to the primary via inner Lagragian point (L1) and the transferred matter forms an accretion disk (for a review, see Warner 1995; Osaki 1996;

Hellier 2001). Among dwarf novae, there exist three subtypes based on their light curves. SU UMa-type dwarf novae, whose orbital period are shorter than 0.1 days in the most cases, are one of the subtypes, characteristic of exhibiting two types of outbursts. One is normal outburst, continuing for a few days. The other is superoutburst, lasting about two weeks, during which modulations called superhumps are shown. The period of the superhumps are a few percent longer than that of the orbital period of the system. This is well explained by a phase-dependent dissipation of a tidally deformed precessing accretion disk. The most acceptable model for SU UMa stars is the thermal-tidal instability model developed by Osaki (1989), well reproducing the majority of observations.

V844 Her was discovered by Antipin (1996) as a variable star near η Her. Antipin (1996) classified the variable, originally named Var 43 Her, as a dwarf nova based on the detection of a long outburst. The light curve in Antipin (1996) is reminiscent of a superoutburst of SU UMa-type dwarf novae. Time-resolved CCD photometry was performed by Kato, Uemura (2000) during the 1999 September outburst of V844 Her. Detecting superhumps with a period of 0.05592(2) days, they firstly confirmed the SU UMa nature of V844 Her. By radial velocity studies Thorstensen et al. (2002) determined 0.054643(7) days (78.69 min) as the orbital period of the system. These results indicate that V844 Her is one of the shortest periods among dwarf novae ever known. In order to thoroughly investigate the short period system, the VSNET (Kato et al. 2004) has placed V844 Her as one of the highest priorities since the confirmation of the SU UMa nature of the system. In 2002 May, 2002 October, and 2003 October, V844 Her underwent an outburst and the VSNET Collaboration Team detected superhumps during these superoutbursts.

On 2006 April 24, Pavol A. Dubovsky reported a brightening of V844 Her (12.4 mag) to the VSNET ([vsnet-alert 8914]). Thanks to this prompt report, as well as the seasonal condition of V844 Her (the precise coordinate is RA: $16^{\mathrm{h}}25^{\mathrm{m}}01^{\mathrm{s}}.75$, Dec: $+39°09'26''.4$, Adelman-McCarthy et al. 2006), we firstly succeeded in observing almost the whole superoutburst of V844 Her. The object is identical with USNO A2.0 1275-8931436 (B = 16.9, R = 16.2). The infrared counterpart of the binary is 2MASS J16250181+3909258 (Hoard et al. 2002; Imada et al. 2006a). V844 Her is also catalogued as a bright X-ray source by ROSAT, 1RXS J162501.2+390924 (Voges et al. 1999).

2. Observations

Time-resolved CCD photometry during outburst was performed from 2002 May 20 to 2006 May 20 using 10-100 cm telescopes at 8 sites. The log of these observations is summarized in table 1. Details of observers are listed in table 2. In total, we observed V844 Her for 31 nights, during which 4 outbursts including one normal outburst were detected. The exposure time was 10-40 seconds. The read-out time was typically a few seconds. The resultant cadence is much shorter than the time scale of variations that we focus on. Photometric data were obtained through the V filter at the Kolonica Saddle site. The other sites used no filter, which makes the effective wavelength close to that of R_{c}-system. The total data points amounted to 14674, which is the largest data ever obtained for V844 Her.

After subtracting a dark-current image from the original CCD frames, flat fielding was performed as the usual manner. The images obtained by Mhh and KU were processed by the task apphot in IRAF.[1] Kyoto, OUS, RIKEN, and Okayama data were analyzed by aperture photometry using a Java-based software developed by one of the authors (TK). Data of Mie were analyzed using FitsPhot4.1.[2] The Maxim DL[3] and the C−MUNIPACK[4] were used for data obtained at Kolonica Saddle. After correcting systematic differences between sites, the magnitude was adjusted to that of Kyoto system except for 2006 observations, for which the magnitude was adjusted to that of Saitama system. As comparison stars, USNO A2.0 1275-8932542 (RA: $16^{\mathrm{h}}25^{\mathrm{m}}13^{\mathrm{s}}.25$, Dec: $+39°08'52''.2$, V=12.836, $B-V$=0.994) and USNO-A2.0 1292-0262723 (RA: $16^{\mathrm{h}}24^{\mathrm{m}}51^{\mathrm{s}}.25$, Dec: $+39°12'07''.6$, V=12.334, $B-V$=0.662) were used for Kyoto and Saitama system, respectively (Henden, Honeycutt 1997).[5], whose constancy was checked by the local stars in the same images. Heliocentric correction was applied to the observation times before the following analyses.

3. Results

3.1. 2002 May outburst

The light curve during the 2002 May outburst is presented in figure 1. The magnitude declined linearly at the rate of 0.13(1) mag d^{-1} until HJD 2452420, after which the system kept almost constant magnitude until the end of our run. Such a halt is sometimes observed in other SU UMa-type dwarf novae (e.g., V1028 Cyg, Baba et al. 2000. For a comprehensive review, see Kato et al. 2003). On HJD 2452425, 12 days after the detection of the outburst, V844 Her likely entered the rapid decline stage, when the visual magnitude was fainter than 15.

Figure 2 shows the representative light curves during the plateau phase after removing daily decline trends for each run. Rapid rises and slow declines, characteristic of superhumps, are visible. In order to estimate the superhump period, we applied the phase dispersion minimization (PDM, Stellingwerf 1978) method to the prewhitened light curves during the plateau stage. We determined 0.05584(64)d as being the best estimated period of the superhump. The error of the resulting period was esti-

[1] IRAF (Image Reduction and Analysis Facility) is distributed by National Optical Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with National Science Foundation.

[2] http://www.geocities.jp/nagai_kazuo/dload-1.html

[3] http://www.cyanogen.com/products/maxim_main.htm

[4] http://integral.physics.muni.cz/cmunipack/

[5] ftp://ftp.aavso.org/public/calib/.

mated using the Lafter−Kinman class of methods as applied by Fernie (1989). The obtained superhump period was in good agreement with the previous studies (Kato, Uemura 2000; Thorstensen et al. 2002).

We extracted the maximum times of superhumps calibrated mainly by eye. Table 3 shows the timings of the superhump maxima. A linear regression to the observed times yields the ephemeris in the following equation:

$$\mathrm{HJD(max)} = 2452415.0424(15) + 0.055857(23) \times \mathrm{E}, \quad (1)$$

where E is the cycle count of the maximum timings of superhumps, and the values within the parentheses in the right side of the equation denote 1-σ error, respectively. Using the above equation, we derived the $O-C$ diagram illustrated in figure 3, in which the dashed line means the best fitting quadratic equation as follows:

$$\begin{aligned} O-C =& 1.52(0.99) \times 10^{-3} - 1.37(0.40) \times 10^{-4} \times E \\ &+ 1.24(0.34) \times 10^{-6} \times E^2. \end{aligned} \quad (2)$$

The quadratic term yields $P_{\mathrm{dot}} = \dot{P}/P = 4.4(1.2) \times 10^{-5}$, indicating that superhump period increases through the superoutburst. Because of the apparent sparse data listed in table 3, it is likely that the obtained value might include large uncertainty. Nevertheless, we can conclude the conspicuous increase in the superhump period during the plateau stage.

3.2. *2002 October outburst*

Figure 4 shows the light curve of our run during the 2002 October outburst. The outburst was caught on HJD 2452571, when the visual magnitude of V844 Her was about 12.5. Our observations started one night after the detection, when the mean magnitude was about 13.3. Using the data obtained on the first two nights, we determined the mean decline rate to be 1.20(1) mag d^{-1}. The value is large for the plateau stage of a superoutburst in SU UMa-type dwarf novae. On HJD 2452575, V844 Her faded to 17 mag, which is almost the same as that of the quiescent magnitude. Based on the negative observation on HJD 2452570, we can estimate that the duration of the outburst was at most 5 days.

Figure 5 represents the de-trended, enlarged light curves taken on the first two nights. Interestingly, one can see hump-like profiles on 2002 October 25 (HJD 2452573) with the amplitude as large as 0.4 mag. They are, however, definitely not superhumps, since three peaks are detectable with an amplitude of ~ 0.4 mag during the 0.06 days run. These results indicate this outburst was the normal outburst. This is the first recorded *normal outburst* of V844 Her.

3.3. *2003 October outburst*

Figure 6 displays the overall light curves during the 2003 outburst of V844 Her. The duration of the outburst appeared to be about 2 weeks. The decline rate of 0.12(1) mag d^{-1} until HJD 2452945, which is a typical value for SU UMa-type dwarf novae. Due to the absence of observations between HJD 2452945 and HJD 2452951, we cannot specify whether there was a phase of a constant magnitude, as was observed in the 2002 May superoutburst. After the plateau stage, V844 Her entered the rapid decline phase around HJD 2452956, and the magnitude returned to its quiescent level on HJD 2452958. No rebrightenings were observed during our run. Due to the lack of our observations, we were unable to trace superhump period change and whether a precursor was present.

3.4. *2006 April outburst*

3.4.1. *light curve*

The whole light curve of the 2006 April - May outburst is shown in figure 7. The duration of the plateau phase was about 2 weeks. The magnitude declined almost constantly at the rate of 0.15(1) mag d^{-1} from HJD 2453851 to HJD 2453860, after which the magnitude kept almost constant at the end of the plateau stage. On HJD 2453867, V844 Her became faint with the magnitude of 16.5. There provided no evidence of a rebrightening during our run.

3.4.2. *superhump*

Figure 8 shows the enlarged light curves on the first two days of our observations. There is no signal of superhumps on HJD 2453851, while there were hump-like modulations on HJD 2453853. However, their profile suggested that superhumps had not yet fully grown. Then we suppose the superhumps were detected form HJD 2453854.

We performed a period analysis using the 7473 points between HJD 2453854 and HJD 2453864, after subtracting the linear declining trend. The theta diagram of the PDM analysis provides the best estimated period of 0.055883(3)d. This value is in good accordance with that obtained during the 2002 May superoutburst.

Figuer 9 indicates the daily averaged light curves during the plateau phase folded by 0.055883(3)d. A rapid rise and slow decline are a typical feature of superhumps. The data obtained on April 28(HJD 2453854) showed the superhumps with an amplitude of 0.2 mag, then the superhump amplitude decreased gradually. A hint of the regrowth of the superhump can be seen on May 5(HJD 2453861).

3.4.3. *superhump period change*

The superhump maximum timings measured by eye are listed in table 4. A linear regression yields the following equation on the superhump maximum timings;

$$\mathrm{HJD(max)} = 2453854.1284(14) + 0.055885(18) \times \mathrm{E}. \quad (3)$$

The obtained $O-C$ diagram is exhibited in figure 10. For $-1 < E < 128$, the best fitting quadratic equation is given by:

$$\begin{aligned} O-C =& 6.6(0.9) \times 10^{-3} - 3.88(0.34) \times 10^{-4} \times E \\ &+ 3.05(0.27) \times 10^{-6} \times E^2. \end{aligned} \quad (4)$$

This equation yields $P_{\mathrm{dot}} = \dot{P}/P = 10.9(1.0) \times 10^{-5}$, meaning that the superhump period increases through the superoutburst.

3.5. *distance and X-ray luminosity*

It is well known that an accurate estimation of the distance to the dwarf novae is not easy. Nevertheless, we can roughly estimate it using an empirical relation derived by Warner (1987) as follows:

$$M_{\mathrm{V}} = 5.64 - 0.259P, \tag{5}$$

where M_{V} is the absolute magnitude at the maximum during a normal outburst, and P is the orbital period of the system in the unit of hours. The above equation could be applied for the systems which have a low inclination and do not reach the period minimum. Based on the previous investigations by Thorstensen et al. (2002), both conditions can be satisfied for V844 Her. Substituting P=1.3115 into equation (5) and with a little algebra (here we assume that the maximum V magnitude of V844 Her is 12.6), we roughly derived d=290(30) pc as an estimated distance.

Using the obtained distance, we can also estimate the X-ray luminosity of V844 Her following the same manner as Verbunt et al. (1997), who showed that the *ROSAT* PSPC countrate in channel 52-201 corresponds to a flux in the 0.5-2.5 keV bandpass given by

$$\log F_{0.5-2.5\mathrm{keV}}(\mathrm{erg cm^{-2} s^{-1}}) \sim \log \mathrm{cr}_{52-201}(\mathrm{s^{-1}}) - 10.88, \tag{6}$$

where cr_{52-201} denotes the countrate in channel 52-201. With a little algebra, we can obtain the X-ray luminosity between 0.5-2.5 keV is $10^{31.0\pm0.2}$ erg s^{-1}. Although the observed X-ray luminosity will be affected by some effects including the inclination of the system, the derived value is relatively large compared to other SU UMa-type dwarf novae given by Verbunt et al. (1997).

4. Discussion

4.1. *superhump period change*

Historically, the superhump period had been known to decrease during the course of the superoutburst before the tidal instability was discovered (Haefner et al. 1979; Vogt 1983). The decrease of superhump period was ascribed to shrinkage of the disk radius, or simply a natural consequence of mass depletion from the accretion disk (Osaki 1985). Recently, particularly over the past decade, the picture has been altered since numerous systems showed an increase of the superhump period. Such systems are mainly WZ Sge-type dwarf novae, and SU UMa-type dwarf novae with short orbital periods (Semeniuk et al. 1997; Nogami et al. 1998; Baba et al. 2000; Ishioka et al. 2001; Uemura et al. 2002; Olech 2003; Nogami et al. 2004; Imada et al. 2005; Templeton et al. 2006).[6] Observationally, there appears to be a borderline around P_{sh}=0.063 days below which the superhump period tends to increase (Imada et al. 2005).

Figure 11 illustrates the superhump period derivative against the mean superhump period of SU UMa-type dwarf novae. The value for V844 Her is pointed with the filled circles. In figure 11, V844 Her is likely to lie in the general trend. Hence, we firstly confirmed that V844 Her showed the positive P_{dot} derivative and became the shortest period SU UMa-type dwarf nova that was confirmed to exhibit an increase of the superhump period.[7]

Additionally, we should briefly note on figure 10, where one can see data points departured from the quadratic equation (4), corresponding to $E \sim -20$. Recent CCD photometry indicates that this feature is observed not only for V844 Her, but also for other short period SU UMa-type stars exhibiting the positive P_{dot}. The systems include ASAS 102522-1542.4 (Maehara et al. in preparation), FL TrA (Imada et al. (2006)), ASAS 160048-4846.2 (Imada, Monard 2006; Imada et al. in preparation). Theoretical models suggest a dramatic variation in temperature or pressure in the accretion disk is a possible cause of the superhump period change in this stage (Murray 1998; Montgomery 2001; Pearson 2006). We require further samples in order to discuss the nature of the superhump period change at this early stage.

4.2. *on the nature of V844 Her*

It is well known that SU UMa-type dwarf novae show two types of superoutbursts: superoutbursts with a precursor, and superoutbursts without a precursor, though precursor-main superoutburst is hardly observed. For superoutbursts without a precursor, a handful of systems, especially archetype TOADs WX Cet and SW UMa, show three types of superoutburst: a short superoutburst with a duration as short as 10 days, an intermediate superoutburst continuing for 2 weeks, and a long superoutburst lasting longer than 20 days (Howell et al. 1995). In the case of V844 Her, all the three superoutbursts reported here lasted about 2 weeks, suggesting that these superoutbursts belong to the intermediate category, or V844 Her simply lies in the majority of SU UMa-type dwarf novae.

In order to examine whether V844 Her shows other types of superoutbursts, we extracted the observations reported to AAVSO and VSNET since the 1996 discovery. Table 4 summarizes the recorded outbursts of V844 Her, from which we can properly give a constraint on the durations of outbursts[8]. As can be noticed in table 4, no superoutburst provides evidence for a duration longer than 20 days, and the durations of the superoutbursts appears to converge to 2 weeks. From the archives, we newly discovered two facts. One is that V844 Her shows no precursor. Of course we have overlooked the onset of superoutburst in a few cases, for which we cannot specify the type of superoutburst. However, the absence of a precursor has been confirmed in the most cases of the super-

[6] An increase of the superhump period was originally discovered in OY Car (Krzeminski, Vogt 1985), which had been left behind for a long time.

[7] Here we exclude two systems, V485 Cen and EI Psc, for which the systems are believed to pass through another evolutional sequence Uemura et al. 2002; Podsiadlowski et al. 2003.

[8] As for data obtained before 1996, Antipin (1996) studied Moscow collection of photographic plates and found four outbursts of V844 Her. Two were definitely superoutburst, of which one was superoutburst without a precursor.

outbursts by virtue of the amateur observers. The other is that no rebrightenings have been observed in V844 Her despite careful monitoring of the system since the 1996 discovery (Antipin 1996). Recent extensive studies over the past decades suggest that rebrightenings tend to occur among SU UMa-type dwarf novae with short orbital periods (Kuulkers et al. 1996; Imada et al. 2006b).

The most interesting fact is, although it has been mentioned for a long time, that V844 Her shows almost no normal outbursts (Kato, Uemura 2000; Thorstensen et al. 2002). From the viewpoint of the original thermal-tidal instability model, normal outbursts occur more frequently as the mass transfer rate from the secondary increases (Osaki 1989; Osaki 1995). Further, the optical spectrum of V844 Her suggests a relatively high mass transfer rate (Szkody et al. 2005), which accelerates a circulation on the limit cycle in the Σ-T diagram. From table 4, the supercycle of V844 Her is estimated to be about 300 days, which is in agreement with the previous work (Kato, Uemura 2000). When compared to the other systems having similar supercycles, e.g., Z Cha, the peculiarity of V844 Her becomes much clear with respect to the absence of normal outbursts.

Although we cannot draw a firm conclusion against the infrequent normal outbursts, one possibility is that evaporation in the accretion disk is working well so that a hole is created in the inner region of the disk and avoids an outburst (Meyer, Meyer-Hofmeister 1994; Liu et al. 1995; Lasota et al. 1995; Hameury et al. 1997; Mineshige et al. 1998). The model also suggests large X-ray luminosity (Lasota et al. 1995) and expansion of the accretion disk during quiescence (Mineshige et al. 1998). As for the former, the relatively large X-ray luminosity of V844 Her may be suggestive of the evaporation. The latter should be investigated by peak-separation studies during quiescence.

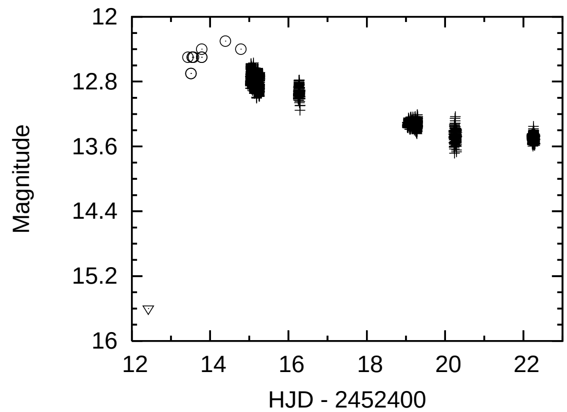

Fig. 1. The obtained light curve during the 2002 May outburst. The abscissa and the ordinate denote the fractional HJD and the magnitude, respectively. The bottom triangle means the negative observation. The opened circles show the visual observations. The light curve shows no sign of precursor.

5. Conclusions

In this paper, we reported on time resolved CCD photometry during 2002 May, 2002 October, 2003 October, and 2006 April outbursts, of which three were superoutburst. We estimated the mean superhump periods of 0.05584(64)d for 2002 May and 0.055883(3)d for 2006 April superoutbursts, respectively. We successfully examined superhump period change during the 2002 May and 2006 April superoutburst. The resultant period derivatives showed an period increase of superhumps during the plateau stages in both superoutbursts, which we confirmed in V844 Her for the first time. We also derived the distance to V844 Her to be 290(30) pc. Using the value, the X-ray luminosity between 0.5 and 2.5 keV is estimated $10^{31.0\pm0.2}$ erg s^{-1}.

To appreciate the long-term behavior of V844 Her, we investigated the archival light curves since the discovery of the variable. Using the extensive data, we estimated a possible supercycle to be $\sim$ 300 days, which is in good agreement with Thorstensen et al. (2002). From the archives, it turned out that V844 Her shows neither precursors nor rebrightenings, although we cannot rule out the possibility that we missed a few events. We also confirmed that V844 Her shows almost no normal outbursts in spite of the intermediate supercycle among SU UMa-type dwarf novae. A possible explanation on the absence of a normal outburst is that the evaporation mechanism may play a role, which is consistent with the relatively large X-ray luminosity of V844 Her. In the future, the evolution of the disk radius during quiescence should be investigated in order to test our suggestion.

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References

Adelman-McCarthy, J. K., et al. 2006, ApJS, 162, 38
Antipin, S. V. 1996, Inf. Bull. Variable Stars, 4360
Baba, H., Kato, T., Nogami, D., Hirata, R., Matsumoto, K., & Sadakane, K. 2000, PASJ, 52, 429
Fernie, J. D. 1989, PASP, 101, 225
Haefner, R., Schoembs, R., & Vogt, N. 1979, A&A, 77, 7
Hameury, J.-M., Lasota, J.-P., & Huré, J. M. 1997, MNRAS, 287, 937

Table 1. Log of observations

Date	* HJD start	* HJD end	†Exp	‡ N	§ ID
2002 May 20	52415.0264	52415.2657	10	1051	KM
21	52416.2469	52416.2942	30	140	Kyoto
24	52419.0356	52419.3031	10	1244	KM
	52419.2251	52419.2973	30	182	Kyoto
25	52420.2194	52420.2997	30	215	Kyoto
27	52422.2133	52422.2934	30	195	Kyoto
2002 October 24	52571.8704	52571.9989	30	122	Kyoto
	52571.9074	52571.9792	10	290	OUS
25	52572.8721	52573.0185	30	261	Kyoto
	52572.9032	52572.9724	10	257	OUS
27	52574.9060	52574.9557	40	89	RIKEN
28	52575.8676	52575.9966	40	222	RIKEN
	52575.8758	52575.9884	30	188	Kyoto
29	52576.8715	52576.9917	30	122	Kyoto
	52576.9266	52576.9620	25-30	77	OUS
30	52577.8781	52577.9332	30	91	Kyoto
2003 October 27	52939.8714	52939.9845	30	185	Kyoto
29	52941.8702	52941.9478	30	148	Kyoto
2003 November 1	52944.8663	52944.9188	30	65	Kyoto
7	52950.8707	52950.9481	30	116	Kyoto
12	52955.8781	52955.9428	30	93	Kyoto
14	52957.8631	52957.8721	30	18	Kyoto
2006 April 25	53851.0347	53851.1642	30	235	Njh
	53851.1684	53851.2948	30	278	Kyoto
	53851.2312	53851.3075	30	124	Mhh
27	53853.0808	53853.3080	30	533	Kyoto
28	53854.0403	53854.1606	30	221	Njh
	53854.1103	53854.2534	30	408	Mhh
	53854.1183	53854.3170	30	373	Kyoto
29	53855.4640	53855.5378	30	107	PD
30	53856.1070	53856.2445	30	506	Mhh
	53856.3505	53856.5867	30	343	PD
2006 May 1	53857.1459	53857.1463	30	200	Mhh
2	53858.0236	53858.1938	30	307	Njh
	53858.1229	53858.3097	30	383	Kyoto
3	53859.0606	53859.1608	30	182	Njh
	53859.0655	53859.2031	30	363	Mhh
	53859.1268	53859.2947	30	192	Kyoto
	53859.1568	53859.3309	30	439	KU
4	53860.0693	53860.2805	30	534	Mhh
	53860.0842	53860.2142	30	237	Njh
	53860.1026	53860.3091	30	498	Kyoto
	53860.1559	53860.3223	30	369	KU
5	53861.0016	53861.2309	30	406	Njh
	53861.0656	53861.3024	30	538	Kyoto
	53861.0755	53861.3121	30	452	KU
	53861.1565	53861.2755	30	312	Mhh
8	53864.1508	53864.2961	30	184	Kyoto
11	53867.0282	53867.2747	30	469	Kyoto
14	53870.0300	53870.1547	30	230	Kyoto
20	53876.1544	53876.3008	30	243	Kyoto

* : Start and end time of the observation. HJD − 2400000.
† : Exposure time
‡ : Number of frames.
§ : ID of the observers. See Table 2.

Table 2. List of observers.

ID	Observer	Site	Telescopes
KM	K. Morikawa	Okayama, Japan	25cm
KU	S. Oizumi + *	Kagoshima, Japan	100cm
Kyoto	A. Imada + †	Kyoto, Japan	40cm
Mhh	H. Maehara	Saitama, Japan	25cm
Njh	K. Nakajima	Mie, Japan	25cm
OUS	K. Tanabe	Okayama, Japan	10cm
PD	P. A. Dubovsky	Kolonica Saddle, Slovakia	28cm & 30cm
RIKEN	K. Torii	Saitama, Japan	25cm

* : observer S.Oizumi, H.Yamamoto, S.Tanada, T.Yasuda, Y.Arao, K.Kodama, M.Suzuki and T.Matsuo.

† : observer A. Imada, K. Kubota, K. Sugiyasu and T. Kato.

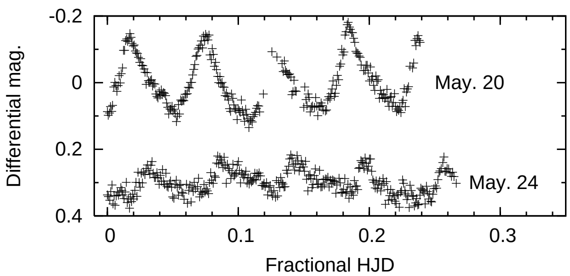


Fig. 2. Representative light curves obtained during the 2002 May superoutburst. The vertical and the horizontal axes denote the fractional HJD and differential magnitude, respectively. For the purpose of a comparison between nights, the light curve on HJD 2452419 (May 24) was shifted by 0.3 mag.

Table 3. Timings of superhump maxima during the 2002 May superoutburst.

E*	HJD†	$O-C$	Error‡	ID
0	2415.0431	0.000700	0.001	KM
1	2415.1019	0.003641	0.001	KM
3	2415.2110	0.001023	0.001	KM
22	2416.2681	-0.003195	0.003	Kyoto
72	2419.0634	-0.000839	0.001	KM
73	2419.1189	-0.001198	0.002	KM
74	2419.1754	-0.000557	0.002	KM
75	2419.2281	-0.003716	0.002	KM
129	2422.2523	0.004105	0.003	Kyoto

* Cycle count.

† HJD-2450000

‡ In the unit of day.

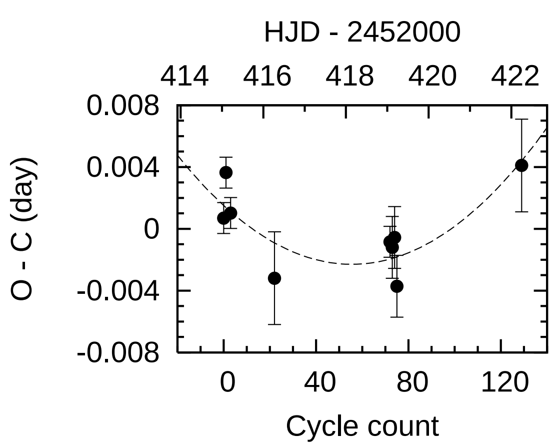


Fig. 3. $O-C$ diagram of superhump maxima. The $O-C$ was calculated against equation (1). The dashed curve is the best fitting quadratic described in equation (2). Note that the superhump period increased as the superoutburst proceeded.

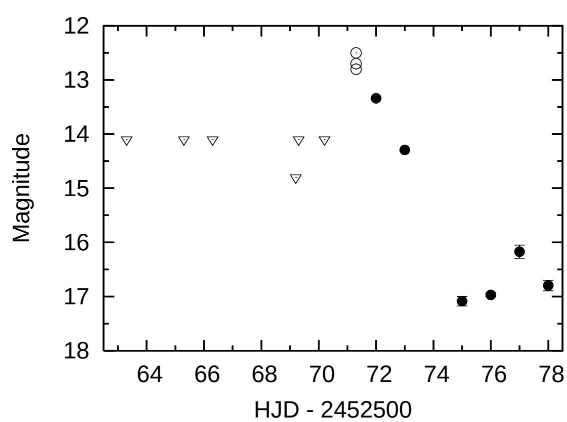


Fig. 4. Light curve during the 2002 October outburst. The vertical and the horizontal axes denote the magnitude and HJD, respectively. The filled circles show the nightly averaged magnitudes. The error bars mean the standard error for each day. The open circles show visual observations. The bottom triangles show the negative observations.

E*	HJD†	$O-C$	Error‡	ID
-18	3853.1201	-0.002163	0.006	Kyoto
-17	3853.1723	-0.005855	0.007	Kyoto
-16	3853.2292	-0.004846	0.005	Kyoto
-15	3853.2893	-0.000638	0.005	Kyoto
-1	3854.0782	0.005781	0.004	Njh
0	3854.1351	0.006789	0.001	Mhh
	3854.1354	0.007089	0.002	Njh
	3854.1356	0.007289	0.002	Kyoto
1	3854.1904	0.006298	0.002	Kyoto
	3854.1905	0.006298	0.002	Mhh
2	3854.2495	0.009506	0.005	Kyoto
3	3854.3027	0.006815	0.003	Kyoto
36	3856.1368	-0.003606	0.002	Mhh
37	3856.1901	-0.006098	0.002	Mhh
41	3856.4149	-0.004964	0.003	PD
42	3856.4693	-0.006456	0.009	PD
43	3856.5204	-0.011247	0.006	PD
70	3858.0322	-0.008419	0.019	Njh
71	3858.0950	-0.001610	0.009	Njh
72	3858.1442	-0.008202	0.004	Njh
	3858.1470	-0.005502	0.004	Kyoto
73	3858.2022	-0.006193	0.004	Kyoto
74	3858.2577	-0.006485	0.005	Kyoto
89	3859.0978	-0.004858	0.003	Mhh
	3859.0984	-0.004158	0.005	Njh
90	3859.1539	-0.004550	0.003	Mhh
	3859.1570	-0.001550	0.005	Kyoto
91	3859.2111	-0.002837	0.003	KU
92	3859.2699	-0.000078	0.002	KU
93	3859.3239	0.001807	0.005	KU
108	3860.1624	-0.002097	0.008	Kyoto
	3860.1670	0.003014	0.002	KU
109	3860.2242	0.003811	0.010	Kyoto
	3860.2243	0.004429	0.002	KU
110	3860.2806	0.004319	0.005	Kyoto
125	3861.1191	0.004446	0.007	Kyoto
	3861.1212	0.007165	0.003	KU
126	3861.1706	0.000055	0.012	Kyoto
	3861.1714	0.000755	0.003	Mhh
127	3861.2305	0.004063	0.004	Mhh
128	3861.2889	0.007209	0.003	KU

* Cycle count.
† HJD-2450000
‡ In the unit of day.

Hellier, C. 2001, Cataclysmic Variable Stars: how and why they vary (Berlin: Springer-Verlag)
Henden, A. A., & Honeycutt, R. K. 1997, PASP, 109, 441
Hoard, D. W., Wachter, S., Clark, L. L., & Bowers, T. P. 2002, ApJ, 565, 511
Howell, S. B., Szkody, P., Sonneborn, G., Fried, R., Mattei, J., Oliversen, R. J., Ingram, D., & Hurst, G. M. 1995, ApJ, 453, 454
Imada, A., et al. 2005, PASJ, 57, 193
Imada, A., et al. 2006a, PASJ, 58, 143
Imada, A., Kubota, K., Kato, T., Nogami, D., Maehara, H., Nakajima, K., Uemura, M., & Ishioka, R. 2006b, PASJ, 58, L23
Imada, A., & Monard, L. A. G. B. 2006, PASJ, 58, L19
Ishioka, R., et al. 2001, PASJ, 53, 905
Kato, T., Nogami, D., Moilanen, M., & Yamaoka, H. 2003, PASJ, 55, 989
Kato, T., & Uemura, M. 2000, Inf. Bull. Variable Stars, 4902
Kato, T., Uemura, M., Ishioka, R., Nogami, D., Kunjaya, C., Baba, H., & Yamaoka, H. 2004, PASJ, 56S, 1
Krzeminski, W., & Vogt, N. 1985, A&A, 144, 124
Kuulkers, E., Howell, S. B., & van Paradijs, J. 1996, ApJL, 462, L87
Lasota, J. P., Hameury, J. M., & Huré, J. M. 1995, A&A, 302, L29
Liu, F. K., Meyer, F., & Meyer-Hofmeister, E. 1995, A&A,

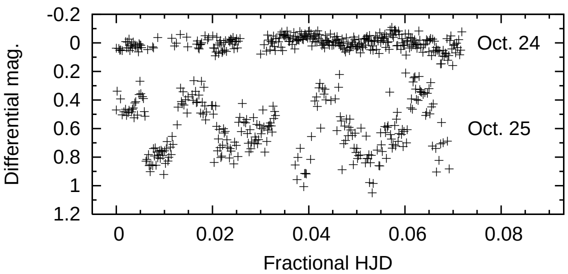


Fig. 5. Enlarged light curves during the first two nights. Hump-like profiles are clearly seen on HJD 2452573 (October 25). The profiles of the humps are clearly different from that of superhumps.

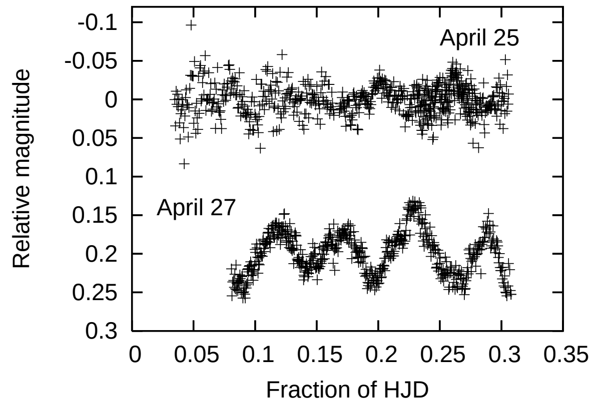


Fig. 8. First 2-days enlarged light curves since we began observing V844 Her. There were almost no feature charactaristics on April 25, while hump-like profiles appeared clearly on April 27.

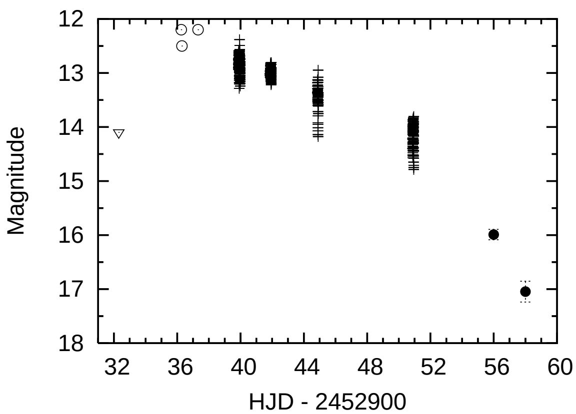


Fig. 6. The resultant light curve during the 2003 October superoutburst. The bottom triangle and the open circles mean the negative and the visual observations, respectively.

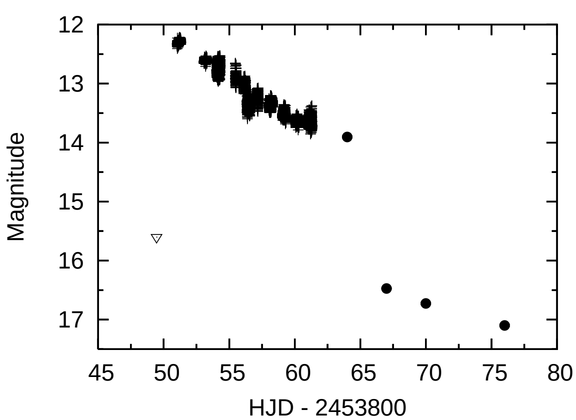


Fig. 7. The whole light curve of the 2006 April-May superoutburst. The horizontal and vertical axes indicate the HJD and the magnitude, respectively. The bottom triangle indicates the negative observation. The filled circles represent the daily averaged magnitude. The typical error bars are within the circles.

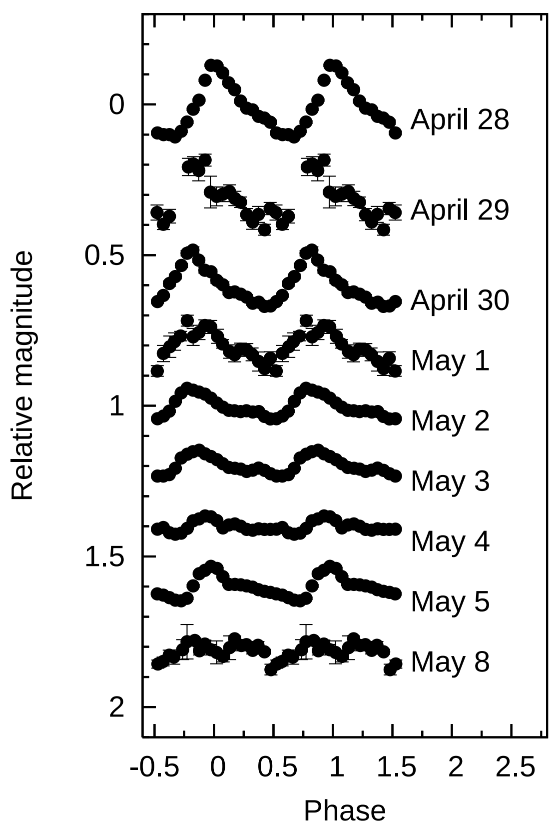


Fig. 9. Daily averaged light curves of the 2006 April-May superoutburst observations.

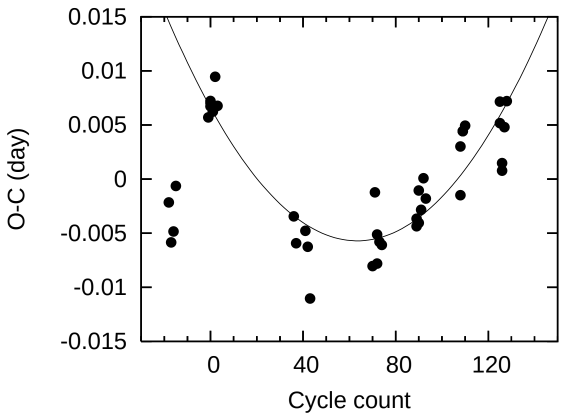


Fig. 10. $O-C$ diagram during the 2006 superoutburst. The horizontal and vertical axes denote the cycle count (E) and $O-C$ (day), respectively. The solid curve is the best fitting quadratic described in equation (4). Note that the superhump period increased as the superoutburst proceeded.

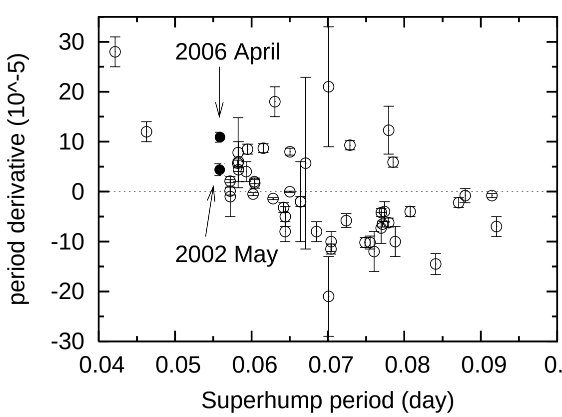


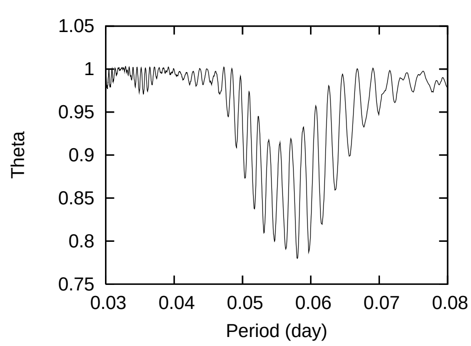
Fig. 11. The $\dot{P}$/P diagram for SU UMa-type dwarf nova. The data points were reference to Uemura et al. (2005). The filled circles denote the data obtained in this work.

Table 4. Recorded outbursts of V844 Her.

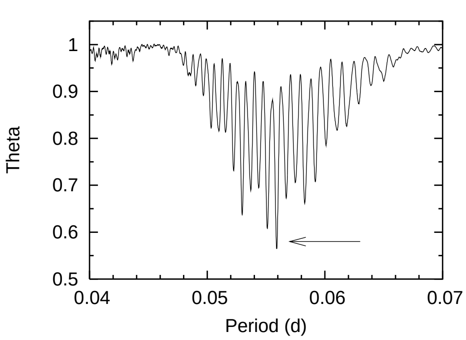
Date		Duration	Type	precursor
1996	October	$7< T <20$	S	×
1997	May	$T =15$	S	×
1998	December	$8< T <19$	S	?
1999	September	$14< T <16$	S	△
2000	July	$16< T <17$	S	×
2001	August	$16< T <18$	S	×
2002	May	$12< T <15$	S	×
2002	October	$5< T <6$	N	–
2002	December	$10< T <18$	S	?
2003	May	$3< T <5$	N	–
2003	October	$12< T <16$	S	?
2005	January	$14< T <16$	S	△
2006	April	$15< T <18$	S	×

S : Superoutburst.
N : Normal outburst.
× : No precursor.
△ : Probably no precursor.
? : Unable to discern the type of superoutburst.

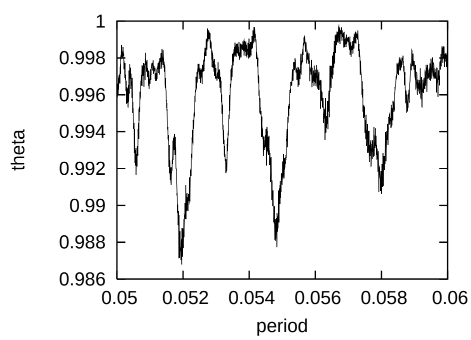
300, 823
Meyer, F., & Meyer-Hofmeister, E. 1994, A&A, 288, 175
Mineshige, S., Liu, B., Meyer, F., & Meyer-Hofmeister, E. 1998, PASJ, 50, L5
Montgomery, M. M. 2001, MNRAS, 325, 761
Murray, J. R. 1998, MNRAS, 297, 323
Nogami, D., Baba, H., Kato, T., & Novák, R. 1998, PASJ, 50, 297
Nogami, D., Uemura, M., Ishioka, R., Kato, T., & Pietz, J. 2004, PASJ, 56, S155
Olech, A. 2003, Acta Astron., 53, 85
Osaki, Y. 1985, A&A, 144, 369
Osaki, Y. 1989, PASJ, 41, 1005
Osaki, Y. 1995, PASJ, 47, L11
Osaki, Y. 1996, PASP, 108, 39
Pearson, K. J. 2006, MNRAS, 371, 235
Podsiadlowski, Ph., Han, Z., & Rappaport, S. 2003, MNRAS, 340, 1214
Semeniuk, I., Olech, A., Kwast, T., & Nalezyty, M. 1997, Acta Astron., 47, 201
Stellingwerf, R. F. 1978, ApJ, 224, 953
Szkody, P., et al. 2005, AJ, 129, 2386
Templeton, M.R., et al. 2006, PASP, 118, 226
Thorstensen, J. R., Patterson, J. O., Kemp, J., & Vennes, S. 2002, PASP, 114, 1108
Uemura, M., et al. 2002, PASJ, 54, 599
Uemura, M., et al. 2005, A&A, 432, 261
Verbunt, F., Bunk, W. H., Ritter, H., & Pfeffermann, E. 1997, A&A, 327, 602
Voges, W., et al. 1999, A&A, 349, 389
Vogt, N. 1983, A&A, 118, 95
Warner, B. 1987, MNRAS, 227, 23
Warner, B. 1995, Cataclysmic Variable Stars (Cambridge: Cambridge UniversityPress)



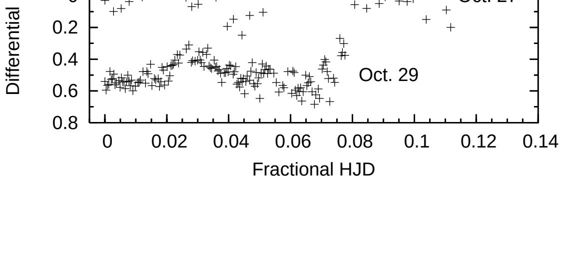
1.05
1
0.95
0.9
0.85
0.8
0.75
Theta
0.03
0.04
0.05
0.06
0.07
0.08
Period (day)



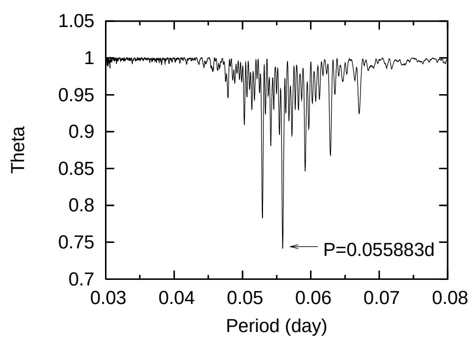
Theta
1
0.9
0.8
0.7
0.6
0.5
0.04
0.05
0.06
0.07
Period (d)



1
0.998
0.996
0.994
0.992
0.99
0.988
0.986
theta
0.05
0.052
0.054
0.056
0.058
0.06
period



Differential mag.
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Oct. 27
Oct. 29
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Fractional HJD



Theta
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.03
0.04
0.05
0.06
0.07
0.08
Period (day)
P=0.055883d